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Oxygen Analyzer Dangerous—Senses Nitrous Oxide as Battery Fails

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Two IL 402§ oxygen monitors, used in the anesthetic breathing circuit, were noticed to malfunction during anesthesia, reporting falsely high O_2 concentrations. Both instruments had been calibrated and the batteries checked prior to anesthetic induction. Since the first malfunction occurred in 1976, before the manufacturer notified users to check possible N_2O sensitivity, we did not check the N_2O zero before use. The second failure occurred recently, and the instrument was shown not to respond to N_2O before induction. In one of these instances, the monitor was being used to control the addition of O_2 to a closed system. This error could have been disastrous. The two cases are presented, together with results of tests done on 15 other IL 402 sensors in our department, and an investigation of the source of the error.

REPORT OF TWO CASES

Case 1. Repair of a retinal detachment in a 32-year-old 65-kg man was begun using spontaneous ventilation in a closed system with a mixture of O_2, N_2O and halothane. One hour after induction of anesthesia, gas flows into the system consisted of 24 ml/min O_2 saturated with halothane, 140 ml/min N_2O, and 250 ml/min O_2. Inspired O_2 was monitored with an IL 402, which had been calibrated prior to induction according to the manufacturer's instructions (not including the subsequently added [after October 1976] test of anesthetic sensitivity). At one hour, the reading was 35 per cent. With no change in gas flow, 15 min later the IL 402 read 46 per cent O_2. The O_2 inflow was decreased to 200 ml/min; 15 min later, the IL 402 read 58 per cent O_2. At this point a Pauling-type (Beckman) paramagnetic oxygen analyzer was connected to the same breathing system as the IL 402, adjacent to it, distal to the inspiratory valve. The O_2 concentration was found to read 25 per cent with this instrument, while the IL 402 registered 62 per cent.

TABLE 1. Oxygen Analysis with IL 402 with a Weak Battery, Compared with a Normally Functioning IL 402 and a Beckman Pauling Paramagnetic Analyzer

Gas Mixture $N_2O/CO_2/O_2$ (l/min)	IL 402 Readings, Per Cent O_2		Beckman Pauling Per Cent O_2
	Battery A 3.54 ± .01 Volts	Battery A 4.05 ± .01 Volts	
3/—/6	100	64	66
3/—/3	100	50	49
1/—/1	96	47	50
1/—/1	84	47	50
6/—/3	100	32	33
6/—/—	88	0	0
—/1/—	2	2	2
—/1/1	46	48	50
—/0.5/1	60	60	66
—/1/.5	33	33	33

* The malfunctioning instrument was calibrated with air and checked with 100 per cent O_2 before each reading.

The IL 402 was removed from the circuit and rechecked. The meter indicated zero when "off", 21 per cent with room air, and 100 per cent O_2 when exposed to pure O_2, without recalibration. The battery check was 84 (normal is more than 82). The reading was also correct when exposed to an air–2 per cent halothane mixture. When exposed to 100 per cent N_2O, the IL 402 indicated 66 per cent O_2. The instrument was then opened and the battery voltages were checked, using a qualitative battery tester that loads the cell (Mid West Electronic Sales, Chicago, Illinois), disclosing a weak battery in position A, the deep battery in the holder. New batteries were inserted. When the IL 402 was recalibrated and reconnected into the anesthetic system, it functioned properly, as it had at the beginning of the anesthetic procedure.

Case 2. Prior to induction of anesthesia, an IL 402 was calibrated following the manufacturer's revised check list, which includes the statement No. 6, "Check anesthetic sensitivity (<1 per cent)." It showed no response to 100 per cent N_2O. It was connected distal to the inspiratory valve in the circle system.

An elective surgical procedure was begun using a semiclosed system, with gas flows during the first hour of 2 l/min N_2O, 1 l/min O_2 and 1 per cent enflurane. Toward the end of the first hour, the IL 402 reading was noticed to be drifting upward from the expected O_2 concentration of 32 per cent, eventually reaching 75 per cent. The flowmeters were repeatedly checked and found to be correctly set, and the inlet tubing was correctly attached to the circle. The IL 402 was removed and again passed tests 1–5, which include battery check, but now it showed a response to 100 per cent N_2O. A second IL 402 was inserted in its place, after checking

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and calibrating, and this correlated with the O_2 concentration in the circle system computed from the gas flows being delivered.

Subsequent Testing of the IL 402 Used in Case 2

In order to confirm this malfunction and investigate it further, a Pauling-type paramagnetic oxygen analyzer was used to sample the inspired gas adjacent to the IL 402, distal to the inspired valve. The IL 402 was recalibrated before each flow change, and its battery voltage was checked and found to exceed 82. The actual voltage of cell A, however was 3.55 v, while cells B and C read 4.05 ± .03 v. The comparisons are presented in table 1.

The only discernible difference in the defective instrument was the low voltage of battery A. When this cell was placed in position B or C, the instrument functioned correctly. The low voltage was not detectable using the battery-check switch, even though it caused N_2O to read 88 per cent O_2.

Effect of Low Battery-A Voltage in Other IL 402 O_2 Analyzers

This weak battery and several others that had been nearly discharged were tested in each of the other IL 402 monitors in our institution, to determine which of them might reduce N_2O despite having passed the battery check and other calibration steps. With a battery voltage of 3.52 ± .03 v, 12 of our 16 IL 402 monitors passed the battery check, and calibrated correctly with air and O_2. However, seven of these 12 failed to indicate <1 per cent in 100 per cent N_2O, reading values between 11 and 88 per cent, as shown in tables 2 and 3. The readings were correct with various mixtures of O_2, N_2, and CO_2 provided N_2O was absent.

Table 2. Battery Check on 15 IL 402's using a Partially Discharged Battery in Position A

IL 402 Number	Battery A Voltage	Battery Check
2110	3.52	84
2118	3.52	83
2119	3.52	84
2139	3.52	83
2140	3.52	86
2164	3.52	84
2188	3.52	81
2190	3.52	84
2350	3.52	83
2353	3.52	81
2357	3.56	85
2358	3.52	82
2360	3.56	82
2363	3.56	82
2364	3.52	82

Table 3. Oxygen Analysis with IL 402's with a Weak Battery A Compared with a Normally Functioning IL 402, a Beckman Pauling Paramagnetic Analyzer, and a Clark Blood–Gas Electrode

IL 402 Serial No.	Calibration 100 Per Cent O_2 (Per Cent)	Battery Check	$N_2O/CO_2/O_2$ (l/min)	IL 402 3.55 Volts Per Cent O_2	Beckman Pauling Per Cent O_2	IL 402 4.05 Volts Per Cent O_2	Blood-Gas Electrode Per Cent O_2
2364	94	83	3/—/3	64	49	50	54.8
	100	83	6/—/—	32	0	0	1
	98	83	3/—/6	72	66	66	69.8
	98	83	6/—/3	44	34	34	32.4
	100	83	—/1/1	49	51	49	49.3
	100	82.5	—/1/0.5	32	33	32	32.1
	100	82.5	Air	22	22	22	23.4
2353	100	83	6/—/—	11	0.5	2	1.8
2110	98	86	6/—/—	62	1	1	1.1
	98	86	3/—/3	66	51	50	55.1
	98	86	Air	22	22	22	23
	98	86	—/1/1	46	50	48	48.7
2363	99	83	6/—/—	32	0	2	1.4
	99	83	3/—/3	67	50	50	53.3
	99	83.5	—/1/1	50	50	50	48.7
	99	83.5	Air	22	22	22	23.1
2358	98	83.5	6/—/—	28	1	0	.8
	99	83.5	3/—/3	67	50	50	52.6
	98	83.5	—/1/1	49	50	50	52.1
	98	83.5	Air	21	21	21	22.6
2118	99	83	6/—/—	14	0	0	2
	99	83	3/—/3	48	50	48	50.4
	100	83	—/1/1	48	50	48	49.7
	99	83	Air	21	21	21	23.3

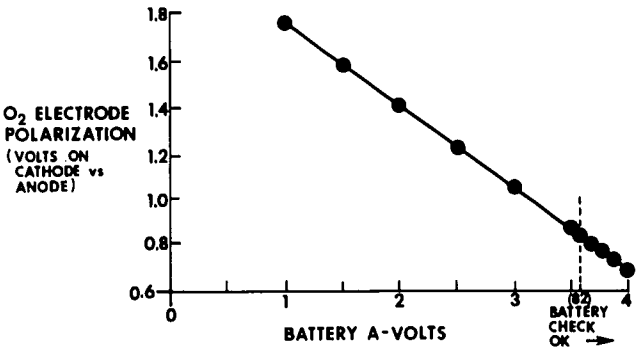

FIG. 1. The effect of failure of the battery A, supplying −4.0 volts in the IL 402 instruments manufactured before November 1976, on the polarization voltage of the oxygen electrode. The battery check test shows the cells in most instruments to be acceptable to a voltage as low as 3.55 v.

TABLE 4. Current Drains of Batteries in IL 402

Cell	Current Drain (ma)		
	Off	Battery Check	On
B	.091	.249	.091
C	.007	.007	<17 (alarm)
A, 4.05 v (0.6 v polarization)	.11	.284	.186 normal .540 max gain, O_2
A, 2.55 v (1.3 v polarization)	.081		.4 max gain, air .65 max gain, O_2

ANALYSIS OF THE PROBLEM

The IL 402 uses a Clark-type polarographic oxygen electrode in which a cathode charged to (nominally) −0.67 v reduces O_2 molecules diffusing to its surface through a water-tight but O_2 permeable membrane (Teflon). A reference electrode (silver) is immersed with the cathode (also silver in this case) in an internal electrolyte. The current generated by oxygen reduction at the cathode is linearly proportional to the P_{O_2} outside the Teflon membrane, and thus it may be calibrated in percentage O_2 in the gas phase.

An oxygen electrode will not reduce N_2O at its normal polarization potential. However, if voltage should rise, a threshold at which N_2O is reduced is reached. The circuit design of IL 402 instruments manufactured prior to November 1976 obtains 0.67 volts for polarizing the reference electrode from a voltage divider between the +4 v B battery and the −4 v A battery, while the amplifier operates to hold the cathode at zero (by current feedback). Battery A, which has a higher current drain than battery B, fails first, and this increases the polarization voltage as shown in figure 1. The drains on the batteries are presented in table 4. Battery A current depends on meter reading, and thus on the gas mixture to which the electrode is exposed. For example, when the electrode is left in 100 per cent O_2, with gain at maximum, battery A consumes about six times as much current as cell B.

Furthermore, as battery A fails, with the resulting increase in the polarizing voltage, the current drain of this battery increases, particularly if it then begins to reduce N_2O. This increase in current thus initiates a more rapid failure, and progressively greater reduction of N_2O.

The relationship of the electrode current to polarizing voltage, and to battery A voltage, is shown in figure 2. The ordinate is the meter reading, which is amplified but is a linear function of electrode current. A voltage increase increases current slightly for O_2 and increases background current (100 per cent N_2) due to evolution of H_2 gas from H^+, but when threshold is reached, a rapid increase in current with N_2O occurs. The threshold and slope of this response may be somewhat variable, for unknown reasons. For example, the electrode tested in Case 2 read 88 per cent O_2 in 100 per cent N_2O at 3.55 v, while the electrode of figure 2 read 40 per cent O_2 in 100 per cent N_2O at 3.55 v. Electrodes in which N_2O is reduced at potentials less than 0.7 v have not been found.

When the IL 402 is turned to the "off" position, some current drain continues, in order to keep the

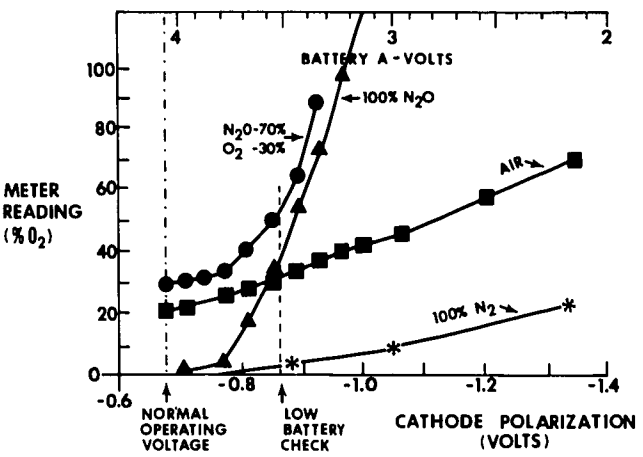

FIG. 2. The polarograms of air, nitrogen and nitrous oxide with an IL 402 oxygen sensor, the increased polarization voltage being produced by failure of battery A (*top abscissa*). The scale was set to read correctly with air. The data points were obtained by simulating battery failure with a variable voltage source, held constant for 2–4 min at each point. Longer stabilization at high voltage reduces the air and N_2 readings but increases the N_2O reading. Furthermore, the 70 per cent N_2O, 30 per cent O_2 mixture yielded a very noisy indication each time it exceeded the 70 per cent reading, jumping upwards about 2–4 per cent for a 1-sec period, then returning to a stable reading for about 5 sec. This suggests that N_2 gas bubbles were being generated beneath the Teflon membrane by N_2O reduction, and the physical motion caused by them changed the reading. This has not been established.

electrode polarized and thus permit it to calibrate immediately when turned on. This current (table 4) is normally about half the "on" current in air, or a smaller fraction of the current in O_2. A theoretical additional source of trouble arises from this situation, in that a battery might weaken during use, go undetected, and regenerate its potential in the "off" position sufficiently to pass all tests, including the N_2O test, when first turned on. The manufacturer states that approximately 60 batteries were subjected to tests to examine for this potential problem, disclosing that when the batteries are discharged two or three times, there is a possibility that it may arise.

The malfunction in Case 2 was not detected at the beginning of the anesthetic procedure using the manufacturer's criteria. The specifications suggest that calibration is needed only every eight hours, yet, in both cases, failure occurred one to two hours after calibration.

This sensitization to N_2O occurring with battery failure is due to a design problem that the manufacturer recognized in 1976 (after an FDA report), and corrected in those model IL 402 and 404 O_2 sensors manufactured after October 1976. In the revised instruments, polarization voltage decreases with battery failure, and N_2O will never be sensed. Clearly this is a highly desirable modification for instruments manufactured before November 1976, which needs only a change of two resistors and relocation of one of their leads. Due to the potentially lethal results of interpreting N_2O as O_2, we believe all of the older instruments should be recalled and modified to prevent such failure.

Since 1976, communication with the manufacturer about this problem has been undertaken by two individuals at our institution. Two notices of the problem have been filed with FDA as well. The manufacturer maintains that the revised check list mounted on the monitor's side, which includes the statement "Check anesthetic sensitivity, <1 per cent, suffices to discharge this obligation. Considering that N_2O is not specifically mentioned, nor is the possibility that it will be detected by batteries that are low but check "OK," or that it may progressively fail with time during use, we cannot agree that these instruments are safe for use in anesthesia where closed-system operation may depend on them for proper O_2 concentration maintenance. We therefore submit this report to alert users of IL 402 and/or IL 404 oxygen monitors to this defect and potential danger. We consider dangerous instruments bearing the following serial numbers:

IL 402: all below 02570
IL 404: all below 02812
Ohio¶ Model 200: all below BAF-D-00918, all BAF-C, all BAF-B, all AAB-A, all AAA-A
Ohio Model 400: all below BAF-D-01287, all BAF-E, all BAF-B, all AAB-A, all AAA-A
Air-Shields**: all oxygen analyzers of IL type

At present, they may be returned for modification at a modest charge.

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Addendum

Since submission of this article to Anesthesiology (and to the manufacturers), the manufacturer has altered the daily check list procedure and offered to modify the polarizing voltage circuit so that nitrous oxide sensitivity is no longer obtained by battery discharge. Clearly this is a highly desirable modification, and the authors strongly recommend that all IL machines manufactured prior to November 1976 have this modification made.

¶ Ohio Medical Products, Division of Airco, Inc., P.O. Box 7550, 3030 Airco Drive, Madison, Wisconsin 53707.

** Narco Air-Shields, Division of Narco Scientific, Hatboro, Pennsylvania 19040.

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Pain Relief by Intrathecally Applied Morphine in Man

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In recent animal experiments, opiate receptors were identified autoradiographically in the brain and the substantia gelatinosa of the spinal cord.[1] In a corollary study, morphine administered directly into the spinal subarachnoid space of the rat produced potent analgesia.[2] Subsequent studies confirmed this finding and showed that repeated intrathecal injections of mor-

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